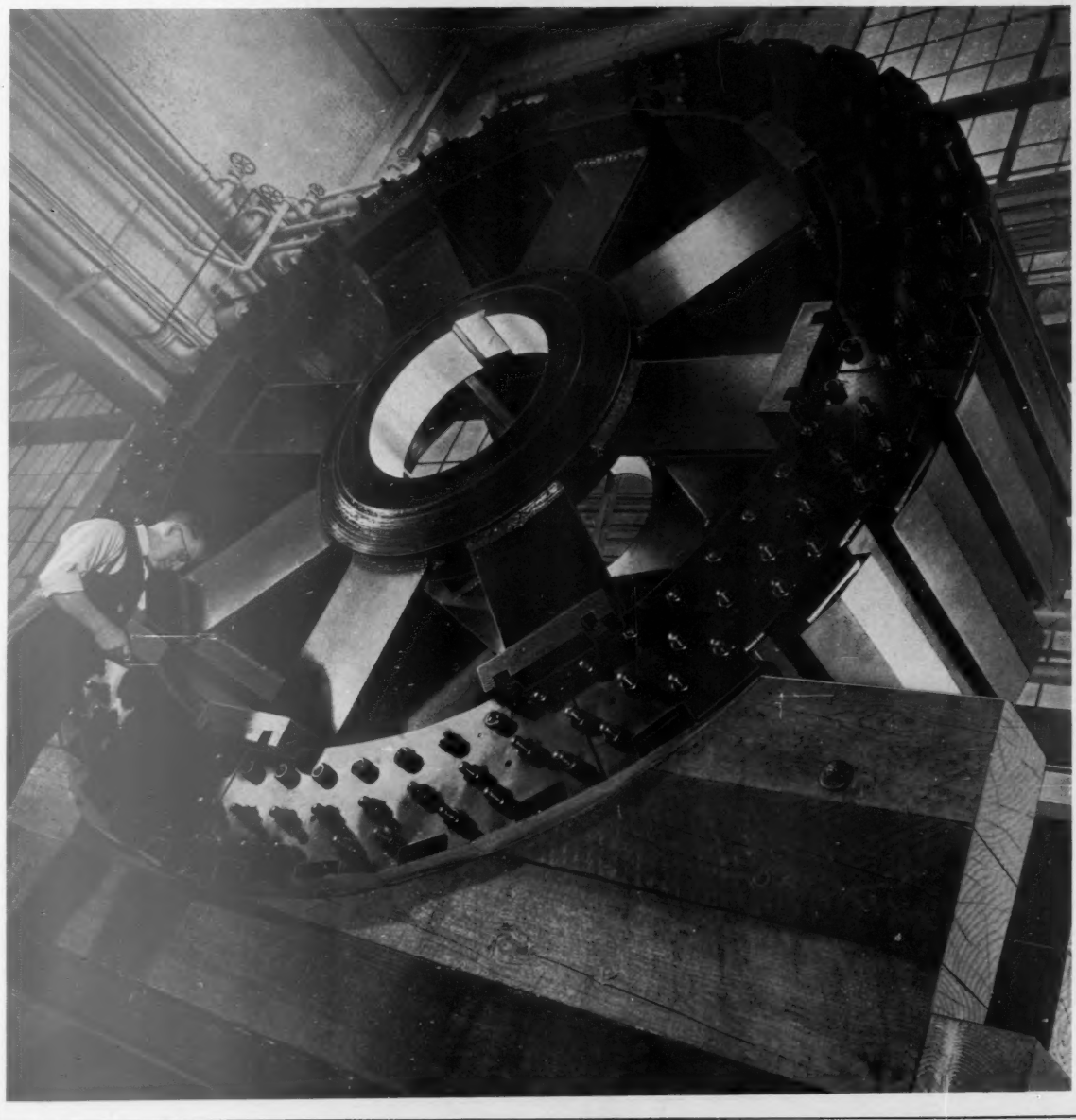
ALLIS-CHALMERS

Electrical REVIEW



First Quarter, 1948

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Electrical Review

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ALLIS-CHALMERS Electrical REVIEW

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Frills JUMP the cost of Autotransformers

L. W. SCHOENIG
Engineer, Transformer Section
Allis-Chalmers Mfg. Co.

Seemingly unimportant details of an autotransformer may greatly affect its cost and size.

CERTAIN factors which have little effect on the size of two winding transformers may have an appreciable effect on the size of autotransformers. Number of taps, loading, power factor, type of operation (step-up or step-down), and full or graded insulation all have a material bearing on size, and consequently the cost of an autotransformer; and frequently the importance of these factors is underestimated in the selection of such a transformer.

A short explanation of the difference between a two winding and an autotransformer may be helpful to better understand an autotransformer and its characteristics.

Know your transformers

The various circuits of a two winding transformer are coupled magnetically whereas in an autotransformer the auto circuits are electrically connected. Diagrams for the two types of transformers are shown in Figures 1 and 2.

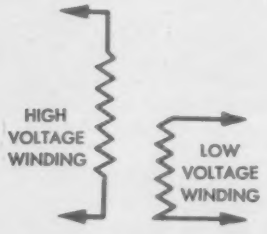
The two winding transformer consists of a high voltage and low voltage winding. An autotransformer consists of a winding which is common to both high voltage and low voltage circuits, a winding which is in series with the high voltage circuits, and usually a tertiary winding. The tertiary winding is delta connected to provide a path for third harmonic magnetizing current, and is used to stabilize the neutral and protect the transformer under short circuits. The usual minimum capacity of a tertiary winding to obtain thermal and mechanical strength under fault conditions is 35 percent of the average kva size of the series and common windings (based on actual kva size, not circuit ratings). The tertiary can also be used to supply loads, in which case its capacity must be designed in accordance with system needs.

Autotransformers are frequently used for loop circuits or interconnecting systems. This is a more efficient, practical means of tying systems together than by doing so with two winding transformers for the ratio of equivalent kva of the autotransformer to the equivalent kva of the two winding transformer is given by

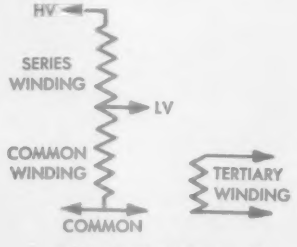
$$\frac{HV - LV}{HV} \qquad (1)$$

The size of the autotransformer will, therefore, be considerably smaller than the comparable two winding transformer. Usually the autotransformer, if the ratio of high to low voltage is not too great, will have lower impedance, lower exciting current, lower core and copper losses and higher efficiency than that of the two winding transformer. Lower impedance is a disadvantage under short circuit conditions, but usually there is sufficient impedance in the system to limit short circuit currents to a value of 25 times normal or less. (All transformers, both auto and two winding, are manufactured to withstand short circuit stresses of at least 25 times normal for two seconds if the impedance is less than four percent.) The lower impedance of the autotransformer has the advantage of contributing to better regulation.

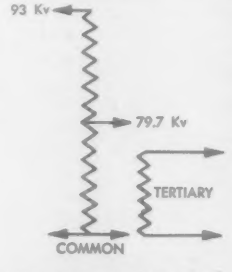
The advantage of lower cost gained in using autotrans-



SIMPLEST FORM of two-winding transformer without taps is shown above. **(FIG. 1)**



AUTOTRANSFORMERS with tertiary winding and no taps are also simple. **(FIGURE 2)**



SIMPLEST VERSION of a 25,000-kva transformer with tertiary, no taps. **(FIGURE 3)**

formers may be lost when the ratio of high to low voltage transformation exceeds two to one.

The equivalent or actual kva's of the parts of the autotransformer are most easily calculated from the voltage and currents of the windings involved. The following equations apply to a step-up or step-down transformer with a minimum capacity tertiary:

KVA_s = Max Ser Wdg Voltage (in kv) × Max Ser Wdg Current = $(HV_{Max} - LV_{Min})\frac{KVA_{HL}}{HV_{Min}}$ (2)

KVA_c = Max Common Wdg Voltage (in kv) × Max Common Wdg Current = $LV_{Max}\left(\frac{KVA_{HL}}{LV_{Min}} - \frac{KVA_{HL}}{HV_{Max}}\right)$ (3)

$$KVA_t = .35\left(\frac{KVA_s + KVA_c}{2}\right) \quad (4)$$

$$KVA = \frac{KVA_s + KVA_c + KVA_t}{2} \quad (5)$$

Where

KVA_s = Series winding kva
KVA_c = Common winding kva
KVA_t = Tertiary winding kva
KVA_{Eq} = Equivalent two winding kva
KVA_{HL} = HV to LV Load kva or thru kva
HV_{Max} = Maximum high voltage tap (kv)
LV_{Max} = Maximum low voltage tap (kv)
HV_{Min} = Minimum low voltage full capacity tap (kv)
LV_{Min} = Minimum low voltage full capacity tap (kv)

Taps affect transformer size

In general there are two types of taps, rated kva and rated current. Rated kva taps are those which will handle the rated kva output of the transformer. For example, a rated kva tap at 90 percent normal voltage will carry 111 percent normal current. Other names for these taps are full kva or full capacity taps. Rated current or reduced capacity taps, as they are frequently called, are those which will handle only the normal current of the transformer (Rated kva ÷ rated voltage). A rated current tap at 90 percent normal voltage will carry only 100 percent normal current. Taps above normal are naturally full kva taps whereas taps below normal can be either full kva or rated current taps.

The addition or omission of no-load taps on a two or three winding transformer has comparatively little effect on its size. The addition of no-load taps in an autotransformer, however, materially affect the size. The effect of the addition of no-load taps can easily be shown by using as an example a 25,000-kva, single-phase 93/161-kv to 79.7/138-kv wye-connected autotransformer with a tertiary of minimum capacity. Figure 3 is an autotransformer with no taps. Equations (2), (3), (4), and (5) are used to calculate the kvas of the various windings and the equivalent kva of the transformer.

$$KVA_s = (93 - 79.7)\frac{25{,}000}{93} = 3{,}575 \text{ kva}$$ from Eq (2)

$$KVA_c = 79.7\left(\frac{25{,}000}{79.7} - \frac{25{,}000}{93}\right) = 3{,}575 \text{ kva}$$ from Eq (3)

$$KVA_t = .35\left(\frac{3{,}575 + 3{,}575}{2}\right) = 1{,}251 \text{ kva}$$ from Eq (4)

$$KVA_{Eq} = \frac{3{,}575 + 3{,}575 + 1{,}251}{2} = 4{,}200 \text{ kva}$$ from Eq (5)

The addition of one 5 percent full kva tap above normal and one 5 percent rated current tap below normal in the high voltage winding is shown in Figure 4. The kva parts and equivalent kva are calculated as before.

$$KVA_s = (97.6 - 79.7)\frac{25{,}000}{93} = 4{,}812 \text{ kva}$$

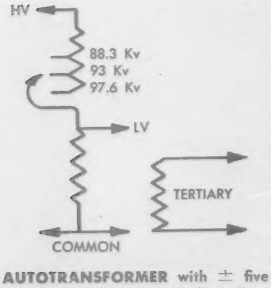
$$KVA_c = 79.7\left(\frac{25{,}000}{79.7} - \frac{25{,}000}{97.6}\right) = 4{,}585 \text{ kva}$$

$$KVA_t = .35\left(\frac{4{,}812 + 4{,}585}{2}\right) = 1{,}644 \text{ kva}$$

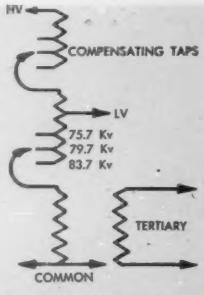
$$KVA_{Eq} = \frac{4{,}812 + 4{,}585 + 1{,}644}{2} = 5{,}520 \text{ kva}$$

If the tap below normal in Figure 4 is a full kva tap

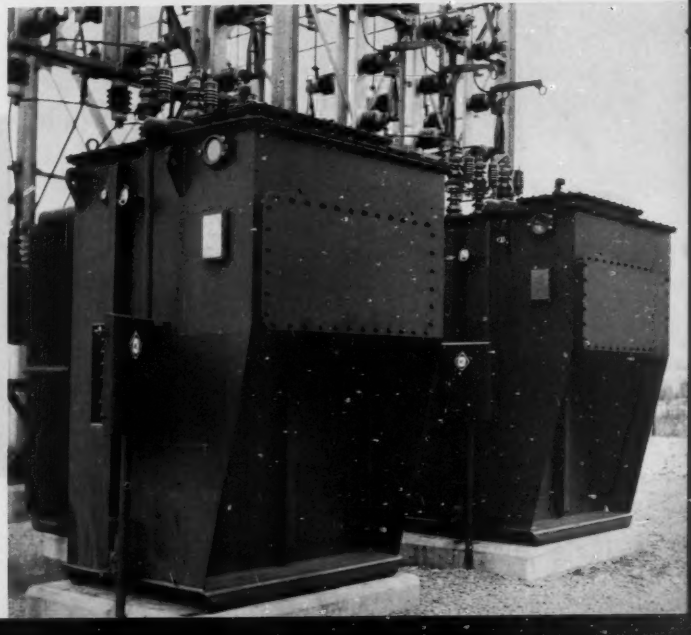
FEEDER VOLTAGE REGULATORS, like the two step-type, three-phase units shown at right, are becoming increasingly prominent in utility systems. Although thousands of them have been installed, the fact that they are autotransformers is still often overlooked. The 600-kva, 7,200-volt units shown are equipped with parallel reactors for parallel operation.

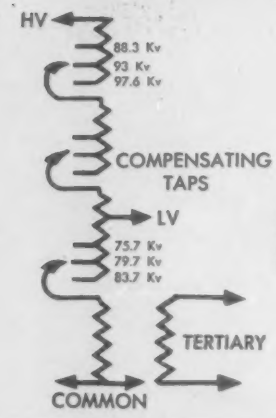


AUTOTRANSFORMER with ± five percent taps in series winding. Taps are normally placed near the winding center for increased impulse insulation strength. **(FIGURE 4)**

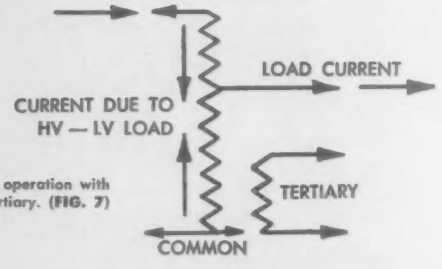


COMPENSATING TAPS in series winding and ± five percent taps in common winding illustrate another autotransformer design. **(FIGURE 5)**

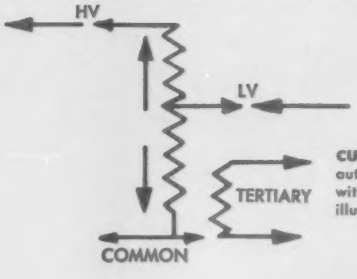




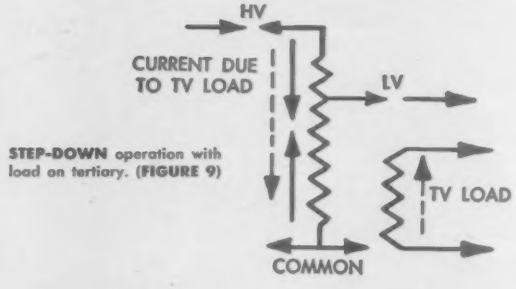
AUTOTRANSFORMER with ± five percent taps in both the common and series winding and compensating taps in series winding. **(FIG. 6)**



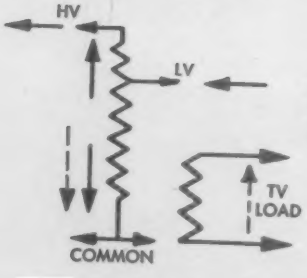
STEP-DOWN operation with no load in tertiary. **(FIG. 7)**



CURRENT DISTRIBUTION of an autotransformer in step-up operation with no load on tertiary winding is illustrated above. **(FIGURE 8)**



STEP-DOWN operation with load on tertiary. **(FIGURE 9)**



STEP-UP OPERATION with load on tertiary. Broken arrows in this and preceding chart represent tertiary current components **(FIG. 10)**

instead of rated current or reduced kva, the kva parts and equivalent kva will increase as follows:

$$KVA_s = (97.6 - 79.7)\frac{25{,}000}{88.3} = 5{,}068 \text{ kva}$$

$$KVA_c = 79.7\left(\frac{25{,}000}{79.7} - \frac{25{,}000}{97.6}\right) = 4{,}585 \text{ kva}$$

$$KVA_t = .35\left(\frac{5{,}068 + 4{,}585}{2}\right) = 1{,}689 \text{ kva}$$

$$KVA_{Eq} = \frac{5{,}068 + 4{,}585 + 1{,}689}{2} = 5{,}671 \text{ kva}$$

Quite frequently taps are needed in the low voltage or common winding. This should be avoided if possible, for when taps are cut in or cut out in the common winding, it is necessary to cut taps out or in in the series winding to keep a constant high voltage. These taps are called compensating taps. One 5 percent full kva tap above and below normal in the common winding is shown in Figure 5. The compensating taps in the series winding are also shown. The kva parts and equivalent are calculated as shown.

$$KVA_s = (93 - 75.7)\frac{25{,}000}{93} = 4{,}650 \text{ kva}$$

$$KVA_c = 83.7\left(\frac{25{,}000}{75.7} - \frac{25{,}000}{93}\right) = 5{,}142 \text{ kva}$$

$$KVA_t = .35\left(\frac{4{,}650 + 5{,}142}{2}\right) = 1{,}714 \text{ kva}$$

$$KVA_{Eq} = \frac{4{,}650 + 5{,}142 + 1{,}714}{2} = 5{,}753 \text{ kva}$$

The addition of a five percent kva tap above and below normal in the high voltage winding in addition to the taps in the preceding example is shown in Figure 6. The kva parts and equivalent kva are calculated as shown:

$$KVA_s = (97.6 - 75.7)\frac{25{,}000}{88.3} = 6{,}200 \text{ kva}$$

$$KVA_c = 83.7\left(\frac{25{,}000}{75.7} - \frac{25{,}000}{97.6}\right) = 6{,}200 \text{ kva}$$

$$KVA_t = .35\left(\frac{6{,}200 + 6{,}200}{2}\right) = 2{,}170 \text{ kva}$$

$$KVA_{Eq} = \frac{6{,}200 + 6{,}200 + 2{,}170}{2} = 7{,}285 \text{ kva}$$

It can be seen from the example that the addition of the taps in the high voltage and low voltage winding increased the equivalent kva of the transformer about 75 percent. This increase is the result of only 10 percent tap range in the high voltage and low voltage winding. As the tap range is increased the equivalent kva is also increased. The equivalent kva is, in general, a good measure of the cost of a transformer, either two winding or autotransformer.

It follows, therefore, that the number of taps and tap range in an autotransformer should be kept to the minimum necessary for good system operation. The voltage should be regulated, if possible, by means other than with the no-load taps of an autotransformer. Voltage regulation can be accomplished by the use of no-load taps on other transformers, the use of regulating transformers, and generator regulation.

Loading for same power factor

An autotransformer with a minimum capacity tertiary has the same high voltage to low voltage capacity when operating either step-up or step-down. The current distribution in the autotransformer is shown in Figure 7 for step-down operation and Figure 8 for step-up operation.

When a load is taken from the tertiary, the high to low voltage capacity depends on the tertiary load and type of operation (step-up or step-down). The current distribution for step-down and step-up operation with a load on the tertiary is shown in Figures 9 and 10 respectively.

It can be seen from Figure 9 that the component of current in the series winding which is due to the tertiary load adds to the component of current due to the high to low voltage load. In the common winding, however, the two components subtract from each other. When operating step-up, as shown in Figure 10, the tertiary load has no effect on the series winding, but adds to the high to low voltage current in the common winding. It should be remembered that the high to low voltage current and the tertiary current are vector quantities and must be added vectorially. If the low voltage and tertiary loads of a step-down autotransformer, or the high and tertiary loads of a step-up transformer are of the same power factor, the component of current due to the tertiary load and the component due to the high to low voltage load can be added arithmetically. If the power factors are not the same, the currents must be added vectorially.

The kva's of the various windings and the equivalent kva of the autotransformer with a load on the tertiary can be calculated by modifying equations (2), (3), (4), and (5).

Step-down autotransformers with tertiary and low voltage loaded at the same power factor:

$$KVA_s = (HV_{Max} - LV_{Min})\frac{KVA_H}{H_{Min}} \qquad (6)$$

$$*KVA_c = LV_{Max}\left(\frac{KVA_L}{LV_{Min}} - \frac{KVA_L}{HV_{Max}}\right) \qquad (7)$$

$$*KVA_c = LV_{Max}\frac{KVA_T}{HV_{Max}} \qquad (7a)$$

$$**KVA_t = .35\left(\frac{KVA_s + KVA_c}{2}\right) \qquad (8)$$

$$**KVA_t = KVA_t\left(\frac{TV_{Max}}{TV_{Min}}\right) \qquad (8a)$$

$$KVA_{Eq} = \frac{KVA_s + KVA_c + KVA_t}{2} \qquad (5)$$

Where

KVA_H = High voltage load kva
KVA_L = Low voltage load kva
KVA_T = Tertiary voltage load kva
TV_{Max} = Maximum tertiary voltage tap
TV_{Min} = Minimum tertiary voltage tap

Step-up autotransformers with the tertiary and high voltage loaded at the same power factor:

$$KVA_s = (HV_{Max} - LV_{Min})\frac{KVA_H}{H_{Min}} \qquad (6)$$

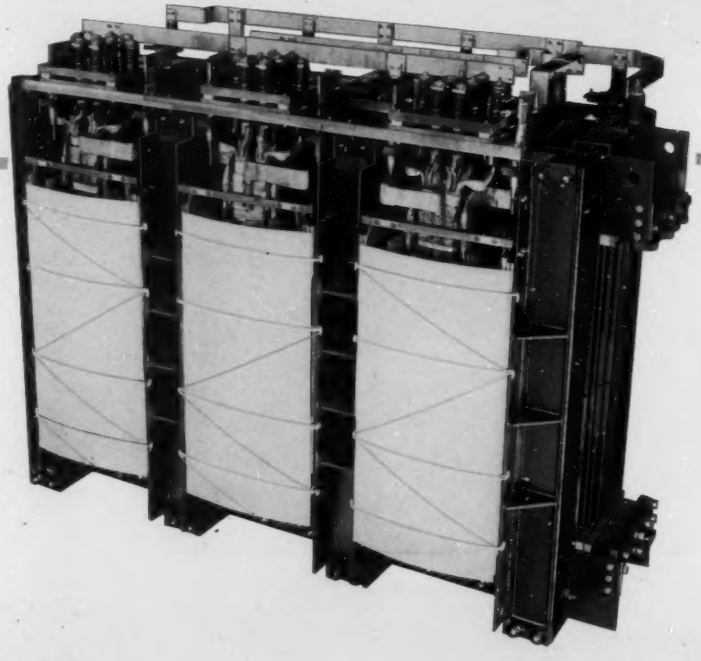
$$KVA_c = LV_{Max}\left(\frac{KVA_L}{LV_{Min}} - \frac{KVA_L - KVA_T}{HV_{Max}}\right) \qquad (9)$$

$$KVA_t = .35\left(\frac{KVA_s + KVA_c}{2}\right) \qquad (8)$$

$$KVA_t = KVA_T\left(\frac{TV_{Max}}{TV_{Min}}\right) \qquad (8a)$$

$$KVA_{Eq} = \frac{KVA_s + KVA_c + KVA_t}{2} \qquad (5)$$

* Use Equation (7) or (7a), whichever is larger.
** Use Equation (8) or (8a), whichever is larger.



CORE AND COILS assembly for a three-phase, 60-cycle autotransformer with a rating of 80,000 kva and 26,400/14,400 volts. Upon completion, unit was placed in operation in a large eastern utility.

The effect of a tertiary load can be shown by comparing the kva size of the windings of an autotransformer when operating step-up or step-down. As an example, consider a 5,000-kva load on the 12-kv delta-connected tertiary of the previous example. When operating step-down, the input to the high voltage will be 25,000 kva and the output 20,000 kva from the low voltage windings and 5,000 kva from the tertiary winding. The kva's of the various windings and the equivalent kva are calculated by using equations (6), (7) or (7a), (8) or (8a), and (5).

$$KVA_s = (93 - 79.7)\frac{25{,}000}{93} = 3{,}575 \text{ kva} \quad \text{from Eq (6)}$$

$$KVA_c = 79.7\left(\frac{20{,}000}{79.7} - \frac{20{,}000}{93}\right) = 2{,}860 \text{ kva} \quad \text{from Eq (7)}$$

$$\text{or } KVA_c = 79.7\,\frac{5{,}000}{93} = 4{,}285 \text{ kva} \quad \text{from Eq (7a)}$$

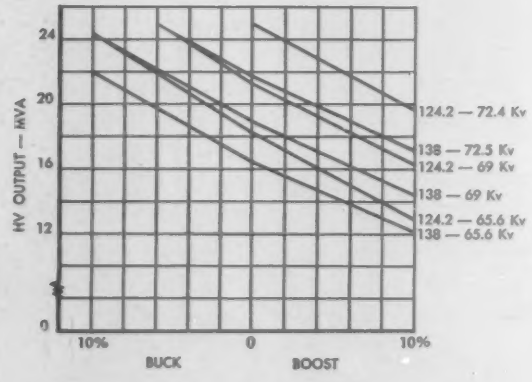
$$KVA_t = .35\left(\frac{3{,}575 + 4{,}285}{2}\right) = 1{,}375 \text{ kva} \quad \text{from Eq (8)}$$

$$\text{or } KVA_t = 5{,}000 \text{ kva} \quad \text{from Eq (8a)}$$

$$KVA_{Eq} = \frac{3{,}575 + 4{,}285 + 5{,}000}{2} = 6{,}430 \text{ kva} \quad \text{from Eq (5)}$$

When operating step-up, the input to the low voltage will be 25,000 kva and the output 20,000 kva from the high voltage winding and 5,000 kva from the tertiary winding. Equations (6), (9), (8) or (8a), and (5) are used to calculate the kva's of the winding and the equivalent kva size.

$$KVA_s = (93 - 79.7)\frac{20{,}000}{93} = 2{,}860 \text{ kva} \quad \text{from Eq (6)}$$



HIGH VOLTAGE CAPACITY permissible for various no-load and load ratio-control tap positions when operating as a step-up autotransformer. **(FIGURE 11)**

$$KVA_c = 79.7\left(\frac{25{,}000}{79.7} - \frac{25{,}000 - 5{,}000}{93}\right) = 7{,}860 \text{ kva} \quad \text{from Eq (7)}$$

$$KVA_t = 5{,}000 \text{ kva} \quad \text{from Eq (8)}$$

$$KVA_{Eq} = \frac{2{,}860 + 7{,}860 + 5{,}000}{2} = 7{,}860 \text{ kva} \quad \text{from Eq (5)}$$

Thus it can be seen that the kva parts are much greater when operating as a step-up transformer if the tertiary is loaded.

The difference between the operating characteristics of an autotransformer when operating step-up or step-down and the effect of load-ratio-control equipment and no-load taps, can further be demonstrated by the case of a 25,000-kva autotransformer recently furnished to a midwest utility. The transformer is a 138-kv to 69-kv, 25,000-kva, three-phase, autotransformer with a 7,500-kva tertiary. The high voltage winding has a 10 percent full kva no-load tap below normal. The low voltage winding has ± five percent full kva no-load taps and ± 10 percent full kva load-ratio-control equipment. The transformer was designed for step-down operation with a maximum simultaneous load of 25,000 kva. When operating step-up with a 25,000-kva input to the low voltage winding and a 7,500-kva load on the tertiary winding at the same power factor as the main circuits, the load which can be taken from the high voltage winding depends upon the position of the load ratio control equipment and also the no-load tap positions. The permissible high voltage load for various no-load tap positions and load-ratio-control positions is shown in Figure 11.

Loading for varied power factor

If the tertiary and low voltage windings of a step-down or tertiary and high voltage windings of a step-up autotransformer are not loaded at the same power factor, special consideration must be given to the calculation of the winding kva's. The following equations can be derived from Figures 9 and 10 which show the current distribution in the transformer due to the high to low voltage and tertiary load.

Step-down autotransformer with the tertiary and low voltage loaded at different power factors:

$$KVA_s = HV_{Max}\, I_s \qquad (10)$$

where $I_s =$

$$\sqrt{(A\cos\theta_L + B\cos\theta_T)^2 + (A\sin\theta_L + B\sin\theta_T)^2}$$

$$KVA_c = LV_{Max}\, I_c \qquad (11)$$

when $I_c =$

$$\sqrt{(C\cos\theta_L - D\cos\theta_T)^2 + (C\sin\theta_L - D\sin\theta_T)^2}$$

$$KVA_t = .35\left(\frac{KVA_s + KVA_c}{2}\right)$$

$$\text{or } KVA_t = KVA_T\left(\frac{TV_{Max}}{TV_{Min}}\right)$$

$$KVA_{Eq} = \frac{KVA_s + KVA_c + KVA_t}{2}$$

Where

$$A = \frac{KVA_c}{HV_{Min}}$$

$$B = \frac{KVA_T}{HV_{Min}}$$

$$C = \frac{KVA_c}{HV_{Max}}$$

$$D = \frac{KVA_T}{HV_{Max}}$$

$\cos \theta_L$ = Power factor of KVA_L
$\sin \theta_L$ = Reactive factor of KVA_L
$\cos \theta_T$ = Power factor of KVA_T
$\sin \theta_T$ = Reactive factor of KVA_T

Step-up autotransformers with tertiary and high voltage loaded at different power factors:

$$KVA_s = (HV_{Max} - LV_{Min}) \frac{KVA_H}{H_{Min}}$$

$$KVA_c = L_{Max}\ I_c \qquad (12)$$

where $I_c =$

$$\sqrt{(E \cos \theta_H + F \cos \theta_T)^2 + (E \sin \theta_H + F \sin \theta_T)^2}$$

$$E = \frac{KVA_H}{LV_{Min}} - \frac{KVA_H}{HV_{Max}}$$

$$F = \frac{KVA_T}{LV_{Min}}$$

$\cos \theta_H$ = Power factor of KVA_H
$\sin \theta_H$ = Reactive factor of KVA_H

Insulation affects price, size

Most autotransformers are wye-connected with the neutral solidly grounded. With this arrangement, graded or reduced insulation on the neutral end of the winding can be utilized. A wye-connected autotransformer which is operated with the neutral isolated cannot utilize the saving effected with graded insulation and must be insulated throughout (both high voltage and low voltage windings) with insulation of the high voltage winding class. The common winding of a wye-connected autotransformer grounded either solidly or through an impedance is insulated with the insulation of the low voltage winding class. Full insulation on an autotransformer will increase the size and cost of the unit from 5 to 30 percent, depending upon the high voltage class and the ratio of transformation. From the standpoint of economics, wye-connected autotransformers with grounded neutrals should not be overlooked.

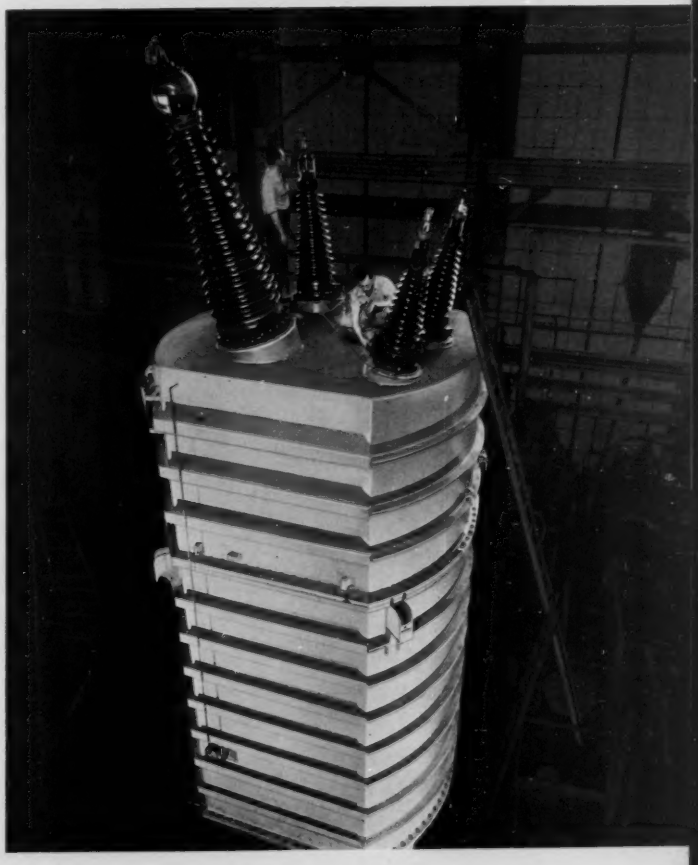
Factors to consider

Autotransformers are unlike two winding transformers in that many factors which have little effect on the size of two winding transformers materially affect the size and cost of the autotransformer. Although four taps and a 10 percent tap range are considered standard on two winding transformers, it is well to omit all taps on autotransformers unless they are specifically required for system operation since the addition of taps increases greatly the size of the autotransformer. Loading, power factor, type of operation (step-up or step-down), and graded or full insulation have a similar effect.

It is very important then, when considering autotransformers, to investigate thoroughly the following factors:

1. No-load taps (type and range)
2. Loading and power factor
3. Step-up or step-down operation
4. Grounded or isolated neutral operation

These factors often change the equivalent kva size and, therefore, the cost of the unit as much as 100 percent.



GRADED INSULATION reduces the cost and size of wye-connected autotransformers. Size of bushings in this 25,000-kva, 230-kv, single-phase unit being set up for chopped wave test illustrates how much inside and outside insulation can be reduced from the line end (230 kv) to the neutral (138 kv) of the high voltage winding. Low voltage bushings are 92 kv.

D-C GENERATORS are an integral part of the propulsion equipment for many of today's car-passenger ferryboats. A recently launched Staten Island-Brooklyn diesel-electric ferry (inset) is equipped with two of the 540-kw, 560-volt, 750-rpm generators shown above. Together they supply two reversible, 685-hp, 700/875-rpm, 560-volt d-c motors which drive the 1,350-shp vessel. Ferry has two propellers, one at each end.

Portable Set Aids Balancing

E. B. MILLS and W. F. KING
Electrical Department, Allis-Chalmers Mfg. Co.

Novel combination of equipment requires no shaft connection.

A COMBINATION of two commercially available pieces of equipment has produced a simple and convenient portable balancing set which is both unique and economically practical. The principal advantages of this set, shown in use in Figure 1, over other portable balancing equipment is that with the new combination no mechanical connection to the shaft is required, thus reducing the set-up time preparatory to balancing to a minimum. It is particularly advantageous where the end of the shaft is not accessible. Furthermore, the components of the set, a vibration displacement indicator and a stroboscopic tachometer, have other useful applications.

Two things must be known for balancing. First, the amplitude of vibration; second, the "high spot," or phase relationship of the vibratory movement to the instantaneous position of the rotating body. Both can be attained with the new portable balancing set.

Determination of the phase relationship has heretofore been accomplished through apparatus connected to the shaft, except for the crude method of scribing the shaft which has several disadvantages. When a stroboscopic lamp has been used in conjunction with a vibration indicator, the flashing of the lamp has been timed by a shaft-driven contactor. The unique feature of the equipment to be described is the combination of two well known instruments together with a simple transformer to produce a balancing set that does not require a shaft connection.

The light band type vibration displacement indicator, such as the Davey vibrometer shown in Figure 2, is both dependable and versatile. Since it is held by hand and requires no mounting, it can be readily applied to measure vibration in any direction. It is not a difficult instrument to operate and can be mastered in a relatively short time.

Vibrometer detects shaft vibration

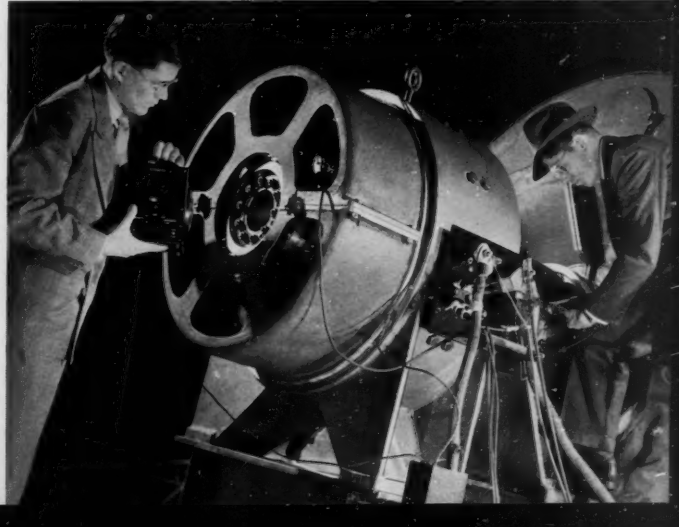
The operating principle of the vibrometer is as simple as its application. A pin projecting from the arm of the vibrometer is pressed lightly against the vibrating object. Movement of the pin actuates a linkage causing a pivoted mirror to oscillate. Light from a small flashlight type lamp is directed at the mirror through a narrow aperture and is reflected from the mirror onto a ground glass scale. Vibratory movement at the pin causes the light to move back and forth on the scale, which, at frequencies of 600 cycles per minute or higher, looks like a continuous band of light.

The usual magnification is 500 to 1. That is, a vibration of .001 inch appears as a one-half inch wide light band on the scale. Since full scale on the instrument is .008 inch, it is necessary that the vibrometer be held steadily.

There is also a neon lamp built into the vibrometer. When the lamp is energized at rotational frequency, each revolution of the shaft produces a red light beam reflected above the white light band. Ordinarily the vibrometer neon lamp and a neon hand lamp are operated by a shaft connected contactor with batteries and an induction coil (Figure 3). In this particular application, the stroboscopic tachometer replaces the function of the contactor and hand lamp.

Stroboscopic tachometer measures speed

Commonly used for observing high speed motion or as a tachometer, the stroboscopic tachometer (Figure 4) consists of a power supply, an oscillator for controlling the frequency of the lamp flashes and a flashing lamp in a single unit. Frequency of the flashing is regulated by a knob on the side and the frequency in rpm is read directly on an illuminated scale. Flashing can also be controlled externally by a contactor for which a connection is provided. A connection is also provided for an auxiliary light for use when more brilliant illumination is desired. This auxiliary light connection is used in the balancing set as the means for energizing the vibrometer neon light as well as synchronizing it with the tachometer.



PORTABLE BALANCING SET at work on a synchronous condenser, with authors of this article demonstrating its application. "High spot" readings are obtained by using the stroboscopic light to illuminate numbers chalked on the commutator of the overhung exciter. **(FIGURE 1)**

Other equipment required includes a six to one ratio transformer. It may be wound with 80 turns of No. 20 wire in the primary and 480 turns of No. 26 wire in the secondary winding with one end of each winding being connected to a common terminal. The transformer is mounted in a small metal case along with two dry cells for the vibrometer white light and off-on switches for control of both vibrometer lights.

When the off-on switch controlling the neon light is closed, it shunts the primary of the transformer so that the switch must be open to operate the light. This arrangement is necessary since the circuit should always be closed to avoid any possibility of malfunctioning of the stroboscopic tachometer.

Connections for the balancing set circuit are simple (see wiring diagram, Figure 5). The neon lamp in the vibrometer is connected to the tachometer in such a manner that it flashes in synchronism with the tachometer light. This is accomplished by means of the auxiliary light connection described above. The step-up transformer is put in this circuit to boost the voltage to that required to fire the vibrometer neon light. The white vibrometer light is connected directly to the dry cells.

Locating vibrations and "high spots"

To use the set there must be some type of reference marking, preferably numbers, on an accessible part of the shaft. Twelve or more divisions should be used. If the vibrometer is applied to the bearing housing with the tachometer in operation, the white light which indicates amplitude of vibration appears as a white band, and the red neon light appears as a red line, as shown in Figure 6a. If the tachometer is adjusted to be slightly out of synchronism with the rotation, the red line will move back and forth across the white band. Then, if the tachometer is adjusted to be synchronized exactly with the machine, the red line will remain stationary at some point along the white band. In other words, when the rotation of the machine, as observed under illumination of the stroboscopic tachometer appears to be stopped, the red line seen in the vibrometer will also be stopped. By adjusting the tachometer then, the red line can be positioned along the white band as desired.

By the mechanism of the vibrometer the light is caused to move from left to right, as seen by the operator in Figure 2, when the vibrating object moves toward the operator. Hence, to find the "high spot" of the shaft the red line is positioned to the extreme right hand side of the white band (Figure 6c). This locates the high side toward the observer and the corresponding shaft number may be read under illumination of the stroboscopic tachometer. In practice, it has been found desirable to adjust the tachometer so that shaft numbers appear to be creeping slowly and thus the red line seen in the vibrometer is moving slowly along the white band. This technique is desirable since exact synchronization for any long period of time is difficult due to slight variations of speed and difficulty of holding an exact setting on the tachometer. Observations with a slightly off-synchronous setting can be made most conveniently by two attendants obtaining simultaneous readings.

COMMERCIALLY AVAILABLE portable balancing set consists of a vibration displacement indicator, neo hand lamp, and shaft operated contactor. Power is supplied by three standard dry cells. **(FIGURE 3)**

Obtaining vibration measurements directly from the shaft is recommended in balancing rotors in relatively rigid bearings. Shaft vibration can be readily measured with the vibrometer by using a graphite brush which has a $\frac{3}{8}$-inch wood dowel stock inserted into it to a depth of about half an inch. The brush is placed in contact with the shaft and the vibrometer pin is applied to the end of the dowel. The graphite brush will ride on the shaft without chattering.

Hand set retains accuracy

When actual balancing is expected to be of long duration and set-up time is of no consequence, a shaft connected contactor may be used in order that one person can obtain the necessary vibration data more easily. When using a commutator type contactor with the set, the stroboscopic tachometer performs the function of a self-powered neon hand lamp. This combination has the advantage of not blurring shaft markings at high speed as is sometimes found in sets using a breaker type contactor and induction coil in conjunction with a neon hand lamp.

Balancing procedure will not be discussed here. For detailed information on methods of balancing, the reader is referred to the appended list of articles. However, there are a few suggestions in regard to balancing conditions that may be helpful. It is desirable in field balancing that data be taken under normal operating conditions, if possible. In any case, the conditions should be held uniform throughout so that any observed change in amplitude and location of unbalance will be as a result of weight changes and not because of the other variables.

In this connection, it is well to observe the effect of load and temperature changes before attempting to balance. If these have a large effect on the smoothness of operation then the possibility exists that there are difficulties other than pure unbalance that should be investigated and corrected before proceeding further. After any abnormal conditions have been eliminated as a source of vibration, mechanical

VIBROMETER can be applied either by holding it in the hands, as shown at left, or by setting the instrument on a base free of vibrations and the pin against the vibrating object. Machine vibrations are amplified and shown on the graduated glass scale. **(FIGURE 2)**

STROBOSCOPIC TACHOMETER measures speed of machines where shaft ends are inaccessible. It is also used for observing high speed motion, measuring speeds from 600 to 14,400 rpm directly. **(FIGURE 4)**

balancing procedure can be continued. The observed amplitude as well as phase angle of unbalance may change considerably with relatively small variation in speed. Therefore, to insure reliable data and effective results it is of primary importance that a constant speed be maintained throughout consecutive balancing runs.

Devising and applying a set of this type to obtain balance data without mechanical shaft connections does not, in any way, sacrifice accuracy. As in the conventional sets, this accuracy is limited by the exactness with which the operator can position the red line in the vibrometer. As the amplitude of vibration decreases, it becomes increasingly difficult to position the red line due to the decreased length of the white line.

While the accuracy with which the phase angle can be determined decreases as the balance is improved, the relative accuracy of the amplitude measurement remains about constant. In general, the "high spot" can be located within plus or minus 15 degrees and the vibration amplitude can be measured within plus or minus 10 percent. It is well to bear in mind the probable error of the data when computing balance correction or erroneous inference may be drawn from an apparent small change in vibration. Accuracy may be improved by taking the mean of a number of successive readings.

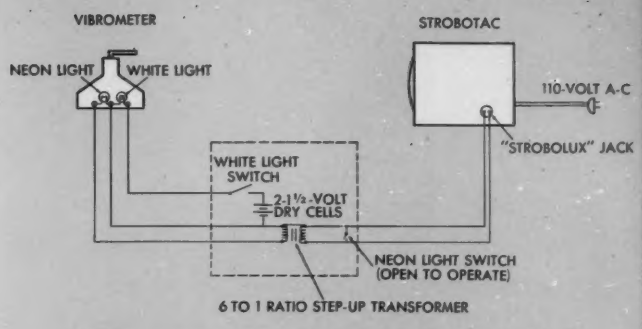
Since this set does not require a shaft connection, it is possible to obtain balance data without stopping the machine being observed, provided there are some visible reference markings on the shaft. Balancing may continue and vibration data may be obtained without taking time to provide for shaft connection; a decided advantage in field balancing. This is, of course, particularly advantageous on equipment where the end of the shaft is not accessible.

Another desirable feature of the portable set is that it is relatively inexpensive. The vibrometer and stroboscopic tachometer are, of course, the major items of equipment but since they can be used extensively individually for many purposes, their usefulness is not limited to the balancing set alone. In many plants, they are standard shop equipment in which case the only expense would be that of the transformer. Because of its simplicity and the variety of applications which component parts make possible, the set can be a valuable production or maintenance aid.

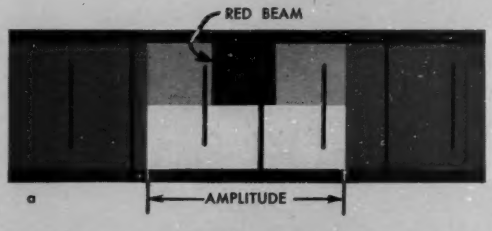
BIBLIOGRAPHY

1. Balancing of Rotating Apparatus I, R. P. Kroon. Journal of Applied Mechanics (New York, N. Y.), Volume 10, Number 4, December, 1943, Page A225.
2. Dynamic Balancing of Rotating Machinery in the Field, E. L. Thearle. Transactions, American Society Mechanical Engineers (New York, N. Y.), Volume 56, 1934, Pages 745-53.
3. Methods of Rotor Unbalance Determination, J. G. Baker, Journal of Applied Mechanics, Trans. A. S. M. E., Volume 61, 1939, Page A-1.
4. Balancing Rotating Machines in the Field, F. C. Rushing and B. A. Rose, Electric Journal, Volume 34, 1937, Pages 441-444.
5. Balancing Is Easy If You Know How, W. F. King, Allis-Chalmers Electrical Review, Second and Third Quarter, 1946, Pages 25-28.

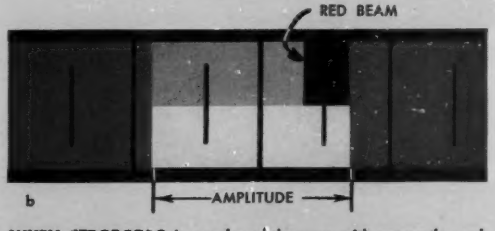
NOTE: Illustrations for Figures 2, 3 and 5 provided by The Vibroscope Co., New York City; Figure 4, by General Radio Co., Cambridge, Mass.



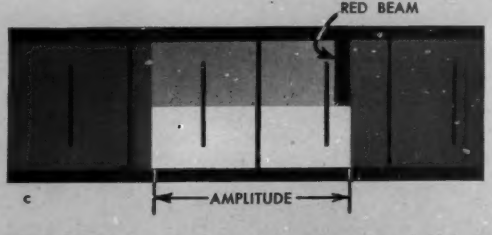
WIRING SCHEME of the portable balancing set shows its simple construction. All items enclosed by the broken lines are mounted together in a small metal case. **(FIGURE 5)**



RED BEAM, as seen on the vibrometer graduated scale, is shown in an intermediate position above the white band, with the vibrometer supported as shown in Figure 2. **(FIGURE 6a)**

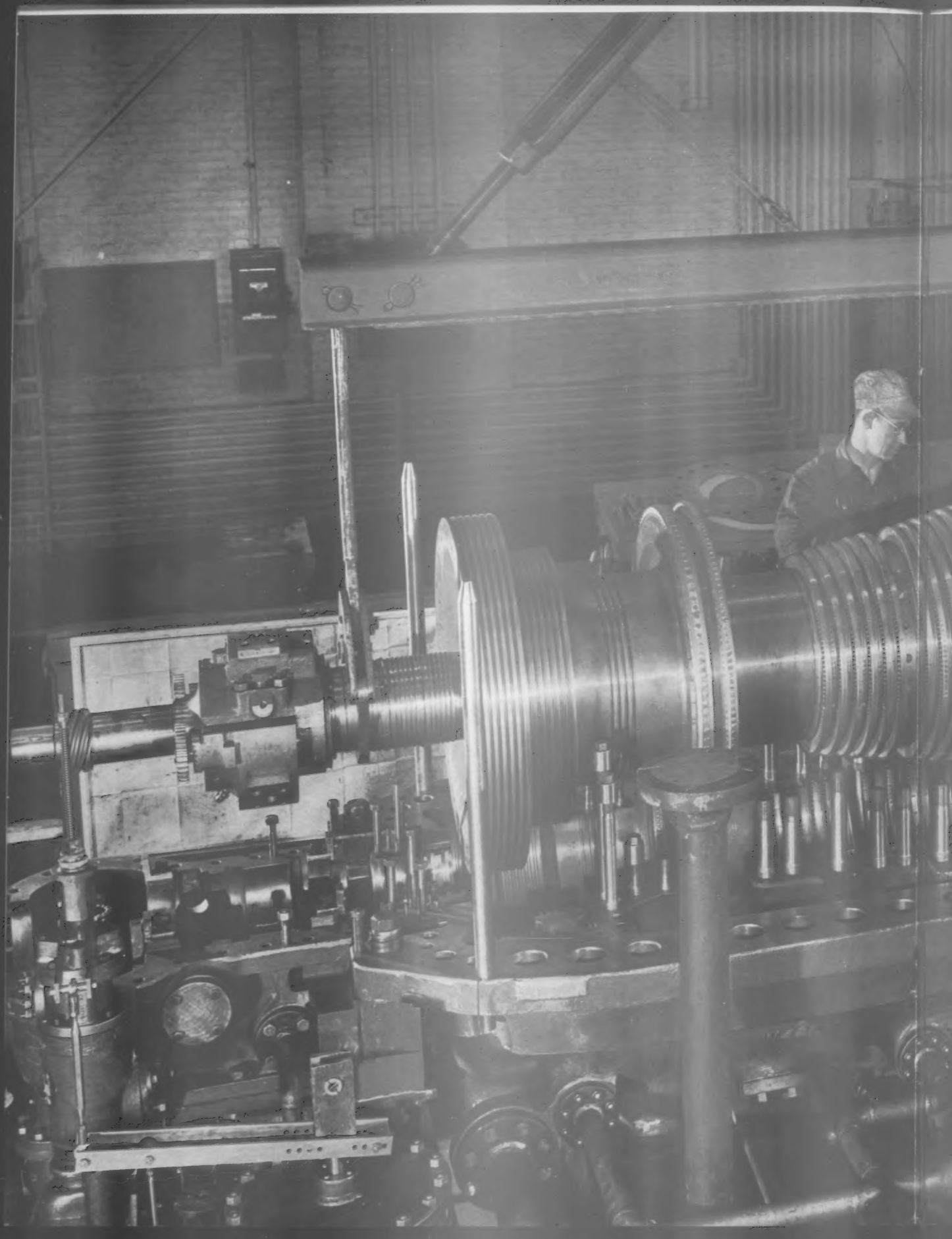


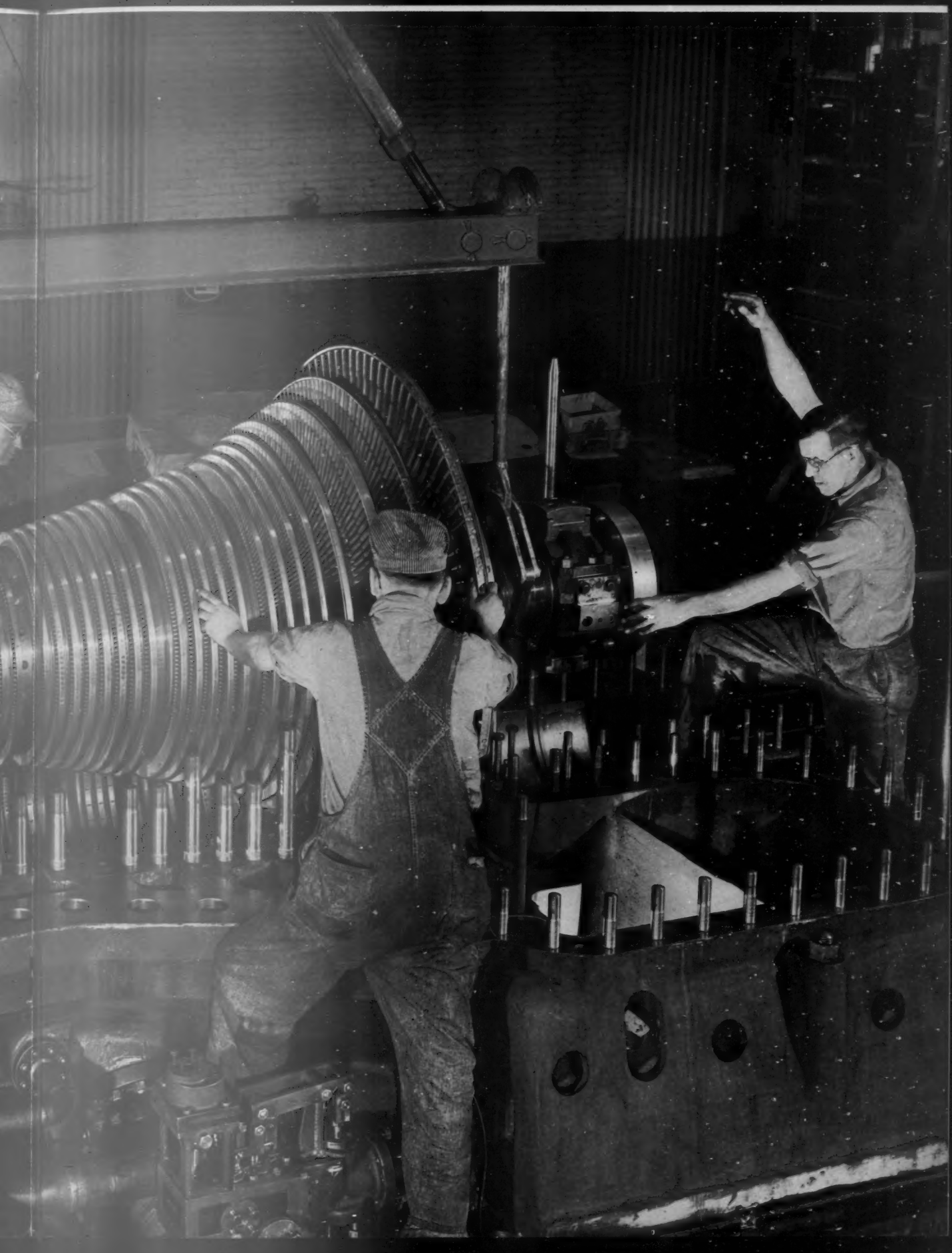
WHEN STROBOTAC is nearly synchronous with rotor, the red beam moves slowly to and fro across white band, completing one cycle as numbers on shaft finish one revolution. **(FIGURE 6b)**



HIGH SPOT is towards observer when vibrometer is held horizontally and red band is at extreme right. When held vertically, red beam should be at the extreme left. **(FIGURE 6c)**

STEAM TURBINE internal construction details stand out in this shop assembly view: the solid forged spindle; individually milled blades of stainless material, with riveted shrouding; separately bolted removable cylinder rings, and combined journal and thrust bearing. Turbine design is typical of units rated 10,000 to 15,000 kw for steam conditions of 600 psig and 825 degrees F. Spindle guides were removed for photo.





Calculating Transformer Rise for Various Loads

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Data obtained from a few simple tests is enough to estimate accurately transformer temperatures for any new load.

FREQUENTLY it is desirable to know what temperature rise a certain transformer will have at some new load, or conversely, what load a certain transformer will carry at a new or different temperature rise. These questions primarily concern oil or liquid immersed, self-cooled transformers of other temperature rise ratings than the standard 55 degrees C temperature rise rating.

Assume for instance that a bank of transformers was purchased at 35, 40 or 45 degrees C rise rating and it now develops that it is desirable to know what load this bank will carry at 55 degrees C rise. The minimum data available usually consists of the no-load loss and the total (full-load) loss in watts, the average temperature rise of the windings and the top oil rise in degrees C at a given load. Various curves have been made to obtain the desired information when loading had sufficient time to reach constant temperature values.

Calculating temperature rises

Transformer temperature rises must be broken into three component parts before calculations can be made. These are (a) temperature rise of the oil, (T_o), above ambient, or room, temperature, (b) temperature rise of windings, (T_c), above ambient temperature, and (c) the difference between these two, commonly referred to as the "copper gradient," (G).

The first of these (a), oil rise, is always measured and reported in factory tests as "top oil rise." The top oil rise for new loadings may be calculated with the aid of formula (1) and the original temperature rise data obtained from factory tests. These calculations are based on normal temperature of the cooling air which at no time should exceed 40 degrees C and the average temperature of the cooling air during any 24-hour period which should not exceed 30 degrees C. For loading oil immersed distribution and power transformers under other conditions of cooling air temperature, refer to the American Standards Association Guides for Operation of Transformers.

The oil rise varies as the 0.8 power of the ratio of total losses of loads, that is:

$$(1)\quad T_{o2} = T_{o1}\left(\frac{W_2}{W_1}\right)^{0.8}$$

Where: T_{o1} is the oil rise in degrees C at initial load or factory test value

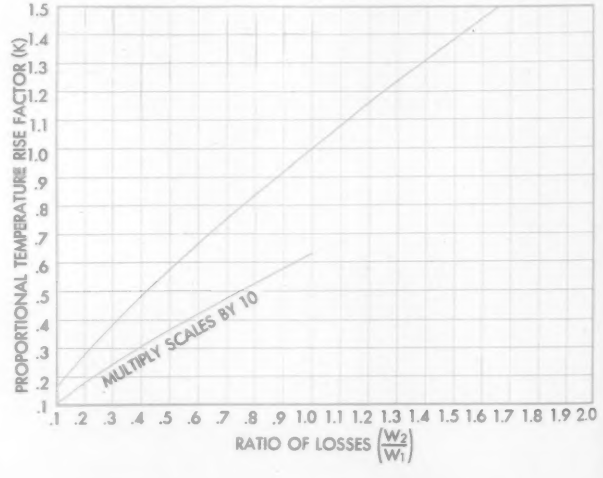
T_{o2} is the oil rise in degrees C at the new load

W_1 is the total loss in watts at initial load or factory test

W_2 is the total loss in watts at the new load

In order to facilitate calculations, this formula has been simplified by the use of the curves, Figure 1. The ratio of losses in watts has been plotted against the proportional temperature rise factor (K), where (K) equals $\left(\frac{W_2}{W_1}\right)^{0.8}$. Thus where (K) is obtained from the curves, Figure 1, we may express formula (1) as follows:

$$(2)\quad T_{o2} = T_{o1}\,(K)$$



TRANSFORMER TEMPERATURE rise calculations can be made shorter when the rise at a given load is known. The rise at another load can be readily determined by multiplying factor (K), taken from the curve opposite the ratio of losses to be dissipated, times the rise of the load which is known. **(FIGURE 1)**

Determining copper gradient rise

The third of these components (c), copper gradient, may be calculated for new loadings with the aid of formula (3) and the original temperature rise data obtained from factory tests. However, we need to explain at this time that transformers of the oil or liquid immersed, self-cooled type should limit the hottest temperatures of the windings to not more than 10 degrees C above their average limiting temperatures. That is, where the average copper rise is 55 degrees C, the hottest copper rise may not exceed 65 degrees C under normal continuous conditions without impairment of the normal life of the transformer.

The true copper gradient may be determined by obtaining the difference between the average copper rise and the "average" oil rise. However, since average oil rise is not a usually or a readily observable value, it has been found by tests that the "average" oil rise (T_{ao}) is approximately 85 percent of the observed top oil rise (T_{o1}). Figure 2 is a representative curve of transformer tank wall temperatures taken at various heights above the transformer tank base. The average oil temperature rise in percent of top oil temperature rise will vary only slightly with a different ratio of copper loss to no-load loss of transformers. However, a somewhat greater variation occurs between relatively short transformers and tall transformers, where the average oil rise in percent of top oil rise will range respectively from approximately 90 percent to 80 percent.

The true copper gradient temperature rise varies as the 0.8 power of the ratio of the copper losses of the loads, that is:

$$(3)\quad G_2 = G_1 \left(\frac{W_4}{W_3}\right)^{0.8}$$

or since copper loss varies as the square of the load, this relationship may be expressed as,

$$(4)\quad G_2 = G_1 \left[\frac{(L_2)^2}{(L_1)^2}\right]^{0.8}$$

and since (K) equals $\left(\frac{W_4}{W_3}\right)^{0.8}$ or $\left[\frac{(L_2)^2}{(L_1)^2}\right]^{0.8}$ we may express formulas (3) and (4) as follows:

$$(5)\quad G_2 = G_1 (K)$$

Where G_1 is the true copper gradient in degrees C at initial load or factory test

G_2 is the true copper gradient in degrees C at the new load

W_3 is the copper loss in watts at initial load or factory test

W_4 is the copper loss in watts at the new load

L_1 is initial load in amperes or percent of initial load

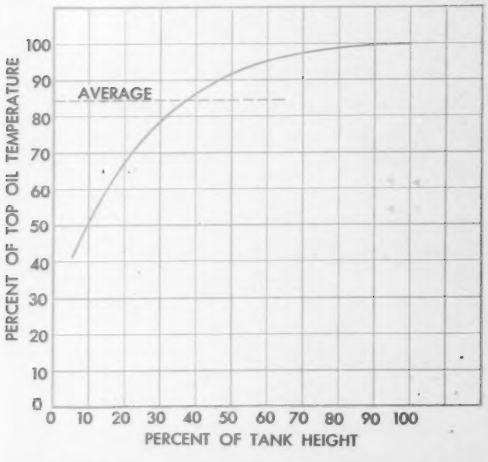
L_2 is new load in amperes or percent of new load

Measuring copper rise

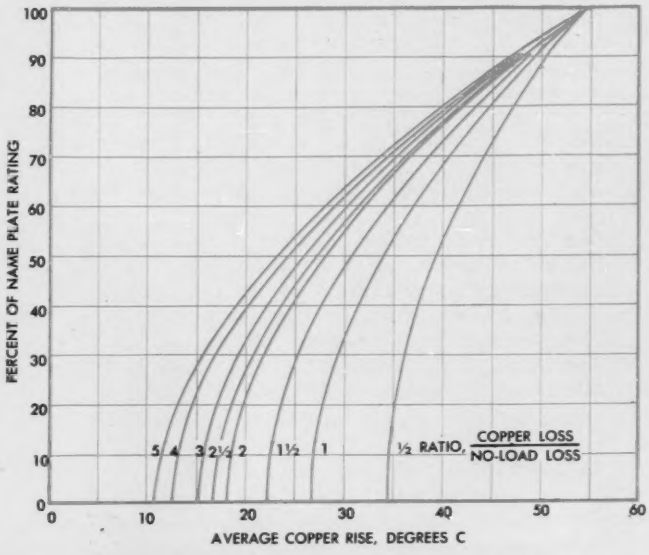
The second component (b), copper rise, is measured and reported in factory tests as "average copper rise." The hottest copper rise (not to exceed 65 degrees C) is the sum of (a), "top oil rise," and of (c), "true copper gradient." Also the average copper rise (not to exceed 55 degrees C) is the sum of (a), "average oil rise," and of (c), "true copper gradient." This relationship may be expressed as:

$$(6)\quad T_c = T_o + G$$

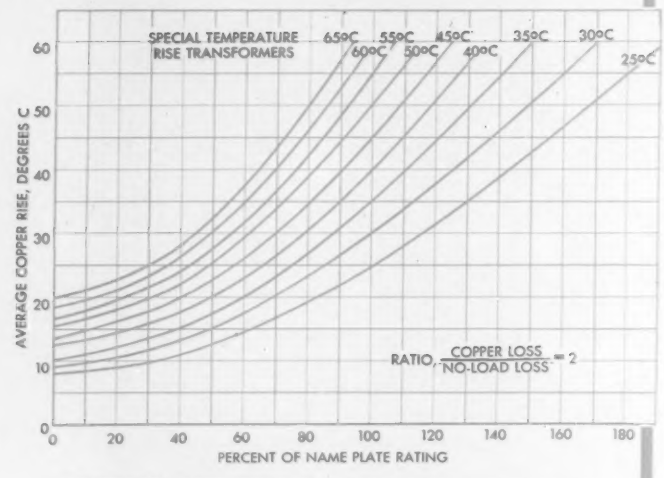
where T_c and T_o are the copper rise and oil rise values under consideration.



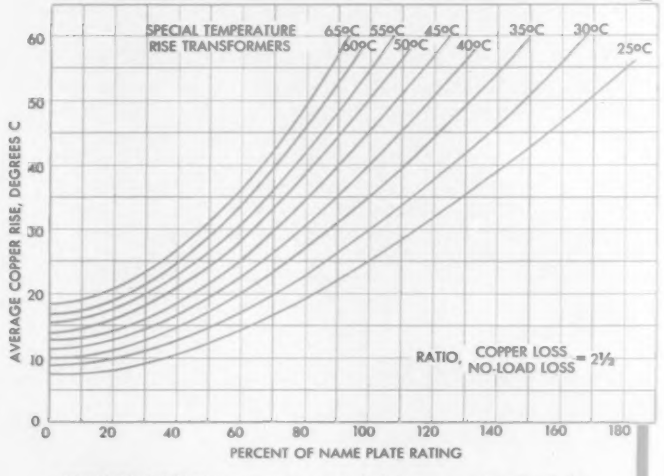
THIS DIAGRAM charts the oil temperature of transformers in percent of "top" or "hottest" oil temperature at various elevations along the vertical tank surfaces. Average temperature of the oil in the transformer may be estimated in this manner. **(FIGURE 2)**


PERCENT OF NAME PLATE RATING
0 10 20 30 40 50 60 70 80 90 100
5 4 3 2½ 2 1½ 1
½ RATIO, COPPER LOSS / NO-LOAD LOSS
0 10 20 30 40 50 60
AVERAGE COPPER RISE, DEGREES C

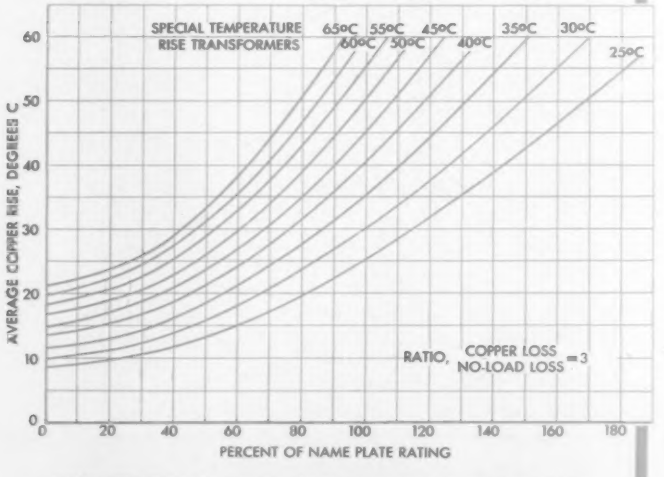
AVERAGE COPPER temperature rise of certain transformers varies at similar load values depending upon the proportion of transformer full-load (copper) loss to no-load loss values. Chart shows this relationship in standard 55 degree C rating transformers at less than full-load. **(FIGURE 3)**


SPECIAL TEMPERATURE RISE TRANSFORMERS
65°C 55°C 45°C 35°C 30°C
60°C 50°C 40°C
25°C
RATIO, COPPER LOSS / NO-LOAD LOSS = 2
AVERAGE COPPER RISE, DEGREES C
PERCENT OF NAME PLATE RATING

INDIVIDUAL PLOTS record the average copper temperature rise at various loads for transformers at temperature rise values indicated. All curves in the diagram are for transformers with a proportion of full-load (copper) loss to no-load loss of two. **(FIGURE 4)**


SPECIAL TEMPERATURE RISE TRANSFORMERS
65°C 55°C 45°C 35°C 30°C
60°C 50°C 40°C
25°C
RATIO, COPPER LOSS / NO-LOAD LOSS = 2½
AVERAGE COPPER RISE, DEGREES C
PERCENT OF NAME PLATE RATING

AVERAGE COPPER temperature rise calculations at various loads for transformers having temperature rise values indicated by curves in the diagram above are for transformers with a proportion of full-load (copper) loss to no-load loss of 2½. **(FIGURE 5)**


SPECIAL TEMPERATURE RISE TRANSFORMERS
65°C 55°C 45°C 35°C 30°C
60°C 50°C 40°C
25°C
RATIO, COPPER LOSS / NO-LOAD LOSS = 3
AVERAGE COPPER RISE, DEGREES C
PERCENT OF NAME PLATE RATING

EACH CURVE in this drawing charts the average copper temperature rise at various loads for transformers having temperature rise values indicated. All curves are for transformers with a proportion of full-load (copper) loss to no-load loss of three. **(FIGURE 6)**

By example, assume a 100-kva transformer with the following data available at 100 percent load taken from factory tests,

No-load loss = 422 watts
Total (full-load) loss = 1,477 watts
Average copper rise = 49 degrees C
Top oil rise = 42 degrees C

What average copper rise will this transformer have when carrying a continuous load of 110 percent?

Referring to the formulas, tabulate the data as given and the data obtainable from the given facts in the order of easy computation.

T_{o1} = 42 degrees C, top oil rise at initial load, — given

T_{ao} = 42 times .85
= 35.7 degrees C, average oil rise at initial load

W_1 = 1,477 watts, total loss at initial load, — given

W_3 = copper loss at initial load
= total loss at initial load minus no-load loss
= 1,055 watts

W_4 = copper loss at new load
= copper loss at initial load $\times \left(\frac{110}{100}\right)^2$
= 1,276 watts

W_2 = total loss at new load
= copper loss at new load plus no load loss
= 1,698 watts

G_1 = true copper gradient at initial load
= average copper rise minus average oil rise
= 49 degrees C minus 35.7 degrees C
= 13.3 degrees C

Taking the ratio of total losses, $\frac{W_2}{W_1}$, or $\frac{1,698}{1,477}$, which is 1.15, to the curve (Figure 1), we obtain (K), the proportional temperature rise factor, value of 1.11 which we use in formula (2) modified to obtain average oil rise (T_{ao1}) for the 110 percent load,

$T_{ao1} = T_{ao}$ (K) $= 35.7 \times 1.11$
$= 39.6$ degrees C, average oil rise at 110 percent load

Continuing calculations in formula (3),

$$G_2 = G_1\left(\frac{W_4}{W_3}\right)^{0.8} = G_1\left(\frac{1,276}{1,055}\right)^{0.8} = G_1\ (1.21)^{0.8}$$

or referring 1.21 to Figure 1, (K) becomes 1.17 and since

$G_2 = G_1$ (K) $= 13.3 \times 1.17$
$= 15.6$ degrees C, true copper gradient at 110 percent load

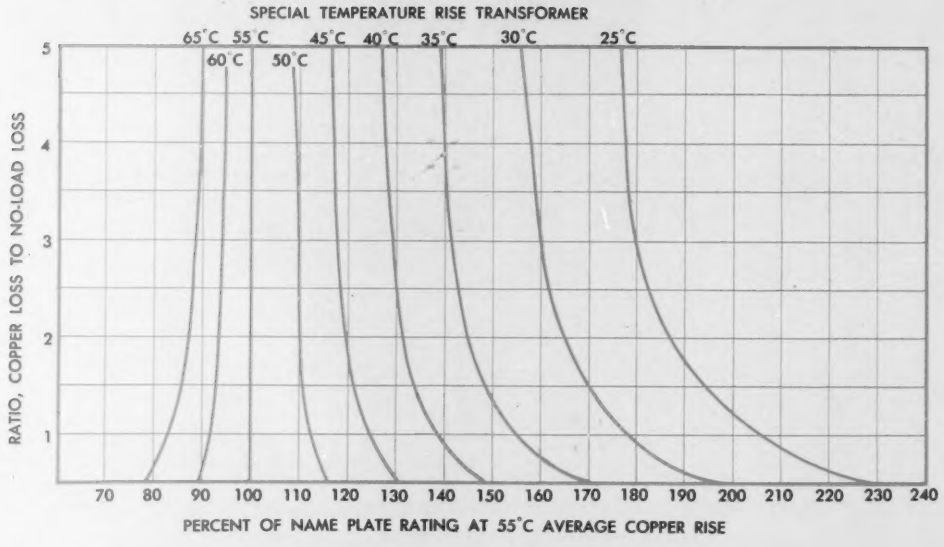
and substituting in formula (6),

$T_{ac} = T_{ao1} + G_2$ where T_{ac} is the average copper rise in degrees C at the 110 percent load,

$T_{ac} = 39.6 + 15.6$
$= 55.2$ degrees C

Suppose we check the hottest copper rise to see if the transformer will exceed the limiting value of 65 degrees C at the 110 percent load.

$T_{o2} = T_{o1}$ (K) where T_{o2} and T_{o1} are the respective



RELATIVE VALUE of loads a transformer will carry depends to some degree on the ratio of full-load (copper) to no-load loss. The top of each curve shows the average copper temperature rise of a transformer at the original full-load rating. Relative value of load which can be carried at 55 degrees C is shown at the bottom from the point on the curve opposite ratio of copper loss to no-load loss. **(FIGURE 7)**

top oil rises for total losses W_2 and W_1.

$T_{o2} = 42 \times 1.11 = 46.6$ degrees C

and substituting in formula (6)

$T_c = T_{o2} + G_2$ where T_c and T_{o2} are respectively the hottest copper rise and the top oil rise at the 110 percent load.

$T_c = 46.6 + 15.6$

$= 62.2$ degrees C

Therefore, the average copper rise of this transformer at 110 percent continuous load is 55.2 degrees C without exceeding the hottest copper limiting temperature rise of 65 degrees C.

Charts verify calculations

So much for the method. Various curves were calculated from the data of modern transformer designs and spot checked by reference to available tests.

One set of curves, Figure 3, shows the average copper rise in degrees C at corresponding "Percent of Name Plate Rating" for standard 55 degrees C rise transformers. There is one curve for each ratio (of copper loss to no-load loss) of ½, 1, 1½, 2, 2½, 3, 4, and 5. These curves indicate that the lower the ratio of copper loss to no-load loss the greater the overload capacity. This conclusion is verified in the succeeding curves.

Another set of curves, Figures 4, 5 and 6, show the average copper rise in degrees C at corresponding "Percent of Name Plate Rating" for various special temperature rise transformers, that is, 25, 30, 35, 40, 45, 50, 55, 60, and 65 degrees C rise ratings. Figures 4, 5 and 6 are companion sets of curves, each separate set has been computed at one certain ratio of copper loss to no-load loss; Figure 4, for a ratio of 2 to 1; Figure 5, for a ratio of 2½ to 1; and Figure 6, for a ratio of 3 to 1.

The last set of curves, Figure 7, shows the "Percent of Name Plate Rating at 55 degrees C Average Copper Rise" obtainable at a range of "Ratio of Copper Loss to No-Load Loss" for various special temperature rise transformers. This set of curves shows clearly the greater overload capacities of the transformers with the lower ratios of copper loss to no-load loss.

Transformer load problems clarified

The following questions and answers serve as examples illustrating each set of curves.

Q. What average copper rise will a transformer have when carrying a continuous load of 110 percent if the no-load loss is 448 watts, the total loss is 1,444 watts and the average copper rise is 45 degrees C?

A. Since the ratio of copper loss to no-load loss has a bearing on the overload capacity, and since the copper loss is 996 watts, this ratio is 2 to 1. Referring to the curves in Figure 4 for this ratio, follow the 110 percent of "Name Plate Rating" point on the abscissa vertically to the 45 degrees C curve and read across to 52 degrees C rise.

Q. Using the data in the previous question, what continuous load will this transformer carry at a temperature rise of 55 degrees C?

A. Referring again to Figure 4, follow the 55 degrees C rise point on the ordinate across to the 45 degrees C curve and then follow vertically downward to the abscissa, 117 percent.

Grouting

PART THREE

LEON A. WATTS
General Superintendent
Service and Erection Department
Allis-Chalmers Mfg. Co.

★

IN practical terms, "grout" is a plastic filler which, under normal circumstances, is poured between a piece of machinery or sole plate and the foundation upon which it is to operate. Being plastic, it is expected to fill all spaces and cavities before it sets or solidifies and becomes, for all practical purposes, an integral part of the principal foundation which has been cast sufficiently in advance of the machine mounting to permit it to sustain its full static load without deformation. Usually, and wherever practicable, the principal foundation is allowed to set through chemical reaction and dehydration for a period of 27 days before loading. The ensuing setting and shrinking process of the mass is very slow, continuing for a period of many years.

Machinery needs attention, too

Previously described steps for preparing machine bases for grouting and the various procedures and ratios of mixtures are essential to good grouting. Techniques and steps involved in readying of equipment for grouting is similarly vital. Although these recommendations and practices may not apply to every type of equipment manufactured, they may be of help to erecting engineers since all grouting jobs are based upon the principle of creating a plastic or fluid connector between the pre-cast base foundation and the equipment to be installed. These suggestions are primarily concerned with the use of cement, sand and water. But grout made with molten sulphur or zinc, lead, iron, and steel turnings mixed with a solution of salamoniac has been successfully applied to meet unusual requirements.

In preparing equipment for grouting, surfaces coming in direct contact should be thoroughly cleaned of oil, paint and mill scale while such surfaces are exposed and accessible to cleaning. This should be done before the machinery is landed on the foundation and over foundation bolts.

Equipment leveling simplified

The conventional method of adjusting frames, sole plates and bases is to use plates, shims and wedges. In nearly all cases, bases and sole plates are drilled and tapped for suitable jack bolts which greatly facilitate their grading, aligning and leveling. Generally, these jack bolts are located and spaced in such a manner as to adjust heavier parts with an occasional jack bolt in the area of the base which is not subjected to concentrated loads. Considerable time and effort could be saved if all equipment were provided with suitable jack bolts. Some types of equipment, however, do not lend themselves to the use of jack bolts.

Assuming that all is in readiness for placing the equipment on the foundation, the drawing should be consulted to determine the area where heavy or concentrated loads will be placed. This section of the foundation should be level and smooth. A plate of suitable size, as thick and large as is practical, should be embedded in a batch of two parts of sand and one part cement mortar with low water content. This plate should be leveled both ways and allowed to set. A similar plate should also be placed adjacent to all foundation bolts to prevent distortion of base or frame when the nuts are tightened. The machine should then be placed on the foundation and shored to proper grade by using plates, shims, jack bolts, or wedges.

In many cases, the grade is obtained from bench marks to the equipment by a surveyor's level or transit. In other cases, especially in self-contained equipment, it is not too important. Sometimes the grade is established by the previously determined location of a companion coupling.

Aligning couplings or gears

At times, the leveling of horizontal equipment becomes complicated, especially where a coupling or gears are involved. Frequently, the adjacent shafts must be located slightly out of level in order to obtain proper vertical coupling or gear face alignment. There are two schools of thought in this connection, both being generally successful, but each with merit for certain conditions.

All horizontal shafts deflect, and if bearings are level the deflections cause the ends to be out of vertical. A pair of two bearing elements such as a motor and a roll, or a hydraulic turbine and a pulp grinder may frequently have their rear bearings elevated to bring coupling faces parallel and vertical. Multiple bearing or long elements, such as line shafting or a string of units, cannot readily be so corrected. The couplings are pulled together to give the effect of a continuous shaft. The latter practice can be applied to two bearing elements also, but this depends on coupling flexibility and relative shaft stiffness.

Part IV will appear in the Second Quarter, 1948 REVIEW.

COILS BY THE HUNDREDS spread out in all directions in the coil storage areas at Allis-Chalmers West Allis Works. In a few days, the step-type feeder voltage regulator production line will have used all the autotransformer coils shown, but more will have taken their place. Heavily loaded power lines throughout the nation have boosted demand for regulating equipment far above prewar figures.

DON'T Overlook Silicone Insulation!

J. L. KUEHLTHAU
Insulation Engineer
Electrical Department
Allis-Chalmers Mfg. Co.

Though costly, silicones are a good answer to needs for high temperature insulation for electrical equipment.

THE use of silicone insulation for motors and generators has made rapid progress within the past several years. Various organizations in the electrical industry have conducted extensive development work on the use of silicones and numerous applications have been and are being made where service requirements and experimental design justify.

Silicone insulation has been successfully applied in equipment operating at 2,300 volts, and in sizes ranging up to 4,000 hp in both a-c and d-c machines. These initial successes indicate that its use is advantageous when:

1. Size and weight must be reduced beyond minimum allowed by other insulations. This means increased operating temperatures beyond the safe limits for either Class "A" or Class "B" insulation.
2. Equipment must operate under abnormally high ambient temperature conditions.
3. Improved moisture resistance beyond that obtainable with conventional varnishes is required.
4. Increased service life and reliability is needed for apparatus that might be subjected to severe overload conditions.
5. Increased service life and reliability is required for apparatus operating under conventional temperature standards.

The problem of when to specify silicone insulation, however, is of much greater concern to purchasers of motors and generators than to manufacturers. Prospective purchasers should, therefore, be familiar with the nature, physical properties and applications of silicone insulation.

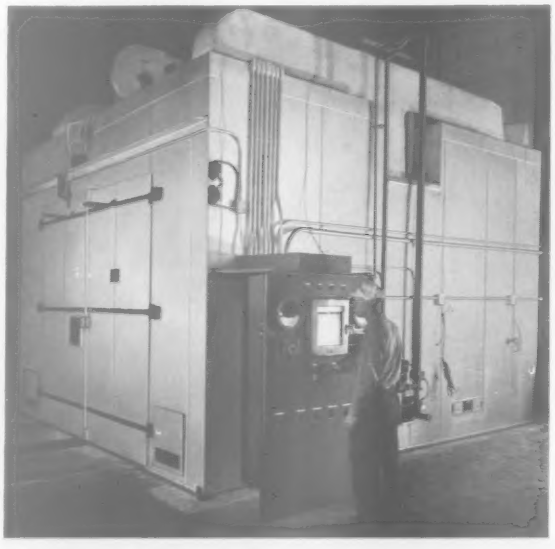
Discovery and early uses

The term silicone embodies a class of synthetic substances having molecular structures built upon a silicon-oxygen framework and possessing properties and characteristics lying between those of mineral silicates and organic plastics. They are neither wholly organic nor inorganic.

The thousands of silicones which have been made to date, and the infinite number which are likely to be produced in the future, are manufactured from sand modified by chemicals made from brine, coal and oil and processed by equipment resembling an oil refinery. Although developed in 1904, by Dr. F. S. Kipping, a professor of chemistry at the University of Nottingham, England, silicone remained virtually unknown to the industrial world until recent years.

Its numerous compounds were largely restricted to experimental purposes during the first decades following its development. Full-scale commercial production did not start until 1944. In spite of the commercial interest shown in the past several years, there are only a few plants producing silicone compounds at the present time.

Industrial application of silicones was spurred by the development, some ten years ago, of fiber-glass materials. The high temperature effectiveness of these materials demanded the development of new, heat resistant varnishes and compounds. Silicones were chosen because of their universally good heat and water resistance, chemical inertness and general stability of physical properties over wide ranges of temperature.



SILICONE INSULATION and silicone insulated machines are processed in car-type, indirect heating ovens equipped with two propane gas heaters rated 1,800,000 Btu/hour each and capable of maintaining a temperature of 600 degrees F. Unit shown above has automatic time cycle control, a complete safety system in its combustion control, plus explosion panels.

Silicone groups vary

In general, silicones may be grouped into four categories: liquids, greases, rubbers and resins. Favorable physical characteristics and properties of each group favor its application as insulation or in some closely related capacity.

Liquid silicones, as a whole, are clear, odorless, inert, heat stable, water resistant and good dielectrics. Available in a wide range of viscosities, they are characterized by their low rate of change in viscosity with temperature, retention of fluidity at low temperatures and non-volatility at elevated temperatures.

Liquid silicones have been used as damping and gauge fluids, mold release agents for plastics, water repellent coatings for ceramics, dielectrics, lubricants for light loads, defoaming agents for lubricating oils, etc. Used as a water repellent coating on electrical insulation, especially on ceramics, liquid silicones maintain higher surface electrical leakage resistance than waxes or glazes.

Silicone greases had their beginning in the development of a heat stable, corona resisting compound for use as a lubricant and filling medium for aircraft ignition cables.

Although it was as soft as ordinary cup grease in appearance, it did not melt or flow, cake or crack on exposure to engine heat. The first silicone greases were not particularly successful for bearing lubrication—the lubricating properties were poor. Silicone greases have now been developed which give good promise of being suitable for high temperature bearing operation. The remarkable feature of these silicone greases is their ability to maintain film characteristics over wide temperature ranges from −70 to +150 degrees C for one type and from −40 to +200 degrees C for another.

Silicone rubbers look and behave a great deal like ordinary natural rubber and are unaffected by high and low temperatures. They retain their elasticity and resiliency almost indefinitely at 150 degrees C, and can be used up to 250 degrees C for certain applications. At minus 50 degrees C they still have approximately their room temperature elasticity and resiliency. While silicone rubbers have excellent heat stability, good arc resistance and good electrical properties, chemical inertness, and waterproofness, they are relatively poor in mechanical strength compared with normal rubbers.

The use of silicone rubber for electrical insulation has been confined, in the main, to cable insulation, insulating gaskets, etc. It will undoubtedly be useful in this field because of the inability of conventional materials to perform under high heat conditions.

Resins differ in characteristics

Silicone resins, the fourth group, are varnish-like liquids which polymerize to a solid when heated. Like the other silicones, the resins exhibit exceptional heat stability and water resistance. Their general physical properties and handling requirements are similar to the better grades of organic resins and oleoresinous varnishes. The silicones, however, require higher curing temperatures and have somewhat lower abrasive resistance, mechanical strength, and oil resistance.

The first of two principal types of silicone resins available is the insulating varnish type—similar to commercial organic oleoresinous baking varnishes. Silicone varnish is available in two forms differing principally in their curing temperatures and their heat stability. One form cures at approximately 150 to 160 degrees C and may be operated continuously at 140 to 150 degrees C and for short times at perhaps 175 degrees C. The second form cures at approximately 250 to 260 degrees C and may be operated continuously at 170 to 180 degrees C and for short periods at perhaps 200 to 225 degrees C. The choice between the two forms is primarily one of available processing equipment and degree of heat stability desired.

SPECIALLY DESIGNED for a forced draft fan drive at an eastern power plant, this 350-hp, 1,160-rpm cage motor is silicone insulated for an ambient temperature of 71 degrees C. Its permissible 85 degrees C rise above the high ambient temperature made possible the construction of a motor considerably smaller than the normal, Class "A" 40 degree rise type.

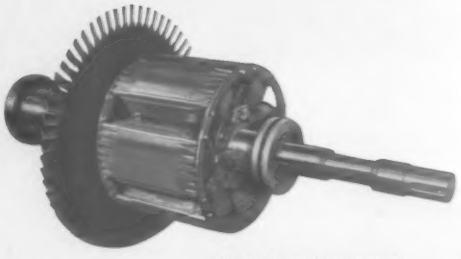
The second type of silicone resin corresponds to the organic thermosetting resins normally used to make rigid laminated or molded insulating sheets or parts. Glass fabric-base silicone-resin-bonded laminates have been produced with fair success. The mechanical strength of the material has not, however, been entirely satisfactory, especially at high temperatures such as are expected in equipment with silicone insulation.

Silicone insulation, in general, consists of combinations of inorganic insulation materials, such as fiber-glass, asbestos, or mica-impregnated, bonded, or coated with a silicone resin. In rotating electrical machinery, silicone insulation is nothing more than standard Class "B" insulation in which the organic resin or oleoresinous bonding or coating medium has been replaced by a silicone resin and all organic supporting material has been eliminated or replaced by inorganic materials. What are the basic advantages of silicone insulation?

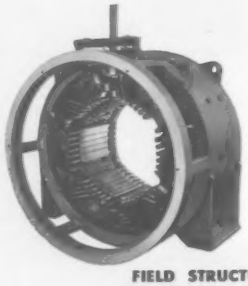
Outstanding because of its heat stability and moisture resistance, silicone insulation generally offers a temperature advantage of 50 to 75 degrees C over conventional Class "B" insulation.

In physical properties, such as dielectric strength, mechanical strength, chemical inertness, and oil immunity, silicone insulation is generally comparable to standard commercial Class "B" insulation. The processing and handling are very similar.

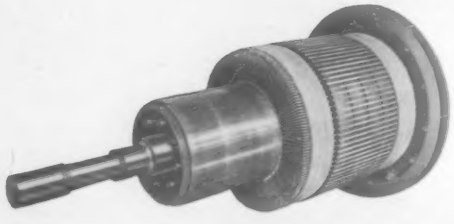
STATOR for a 900-hp, 1,200-rpm, 2,300-volt synchronous motor shows the frame size reductions permissible when using silicone insulation.



SILICONE INSULATION is also applied to field structures. Insulation is baked in ovens at temperatures up to 600 degrees F.



FIELD STRUCTURE for a silicone insulated d-c motor now used for excitation, condenser starting and emergency power supply.



ARMATURE and preceding field structure represent working parts of a 1,000-kw, 1,200-rpm, 500-volt d-c motor in its pre-assembly form.

except that higher curing temperatures are required for silicone insulation.

So successful has been its application that the AIEE is considering adopting a new insulation classification, Class "H," to cover silicone insulation. Tentative temperature limits generally agreed upon are:

	Tentative Class "H"	Class "B"
Hot spot	175—180° C	130° C
Limiting temperature rise	135—140° C	90° C
Hot spot allowance (resistance or detector)	20° C	10° C
Limiting observable temperature rise (resistance or detector)	115—120° C	80° C

Silicone insulation affects design

General forms of silicone insulation now available are: fiber-glass-covered silicone-resin-bonded magnet wire; silicone-varnish-impregnated fiber-glass cloth, sleeving, and tape; silicone-varnish-bonded mica-fiber-glass slot cells; silicone-varnish-bonded mica-fiber-glass tape and cloth; silicone-resin-bonded mica plate; silicone-varnish-fiber-glass cable insulation; silicone-rubber-fiber-glass cloth, and tape insulation.

Before silicone insulation can be used, mechanical design of electrical equipment must be coordinated to allow for increased differential expansion of materials under high curing and operating temperatures. Special bearing construction and lubrication may require consideration, especially in small machines for high ambients. In d-c machines, special attention must be paid to designing the commutator to allow for the increased differential expansion, and copper alloy commutator segments must be used to reduce the annealing effect of the high processing and operating temperatures.

All organic materials, insulating and otherwise, must be replaced with inorganic or silicone materials. Terminal blocks must be made from heat-resistant materials. Cables must be silicone-rubber or silicone-glass-mica insulated. Core lamination insulation must be able to withstand the processing and operating temperatures without shrinking or flowing.

Connections must be soldered with special high melting point solder, or brazed. Bolted connections are unsatisfactory because under high temperatures they become coated with copper oxide, which is a poor conductor.

What about costs and future use?

Because of the many factors involved, it is impossible to offer any rule for estimating the overall cost relationship between conventional machines and equivalent silicone-insulated machines. Perhaps the best practical rule-of-thumb comparison is contained in the statement that silicone-insulated coils cost roughly twice as much as Class "B" coils.

The use of silicone and silicone insulation is continuing on a limited scale where service requirements or experimental design justify it. The results of these applications will be useful in guiding future developments.

It should, however, be remembered that the field of silicone chemistry is comparatively new. Different or improved forms of silicones are likely to be developed which may overcome the limitations experienced with present forms.

Fly-Ash CLEANS *Turbine Blading* Faster

G. V. WILLIAMSON
Superintendent, Steam Engineering
Union Electric Company of Missouri

"Home-made" fly-ash blasting set improves on-the-spot cleaning of stationary turbine blading.

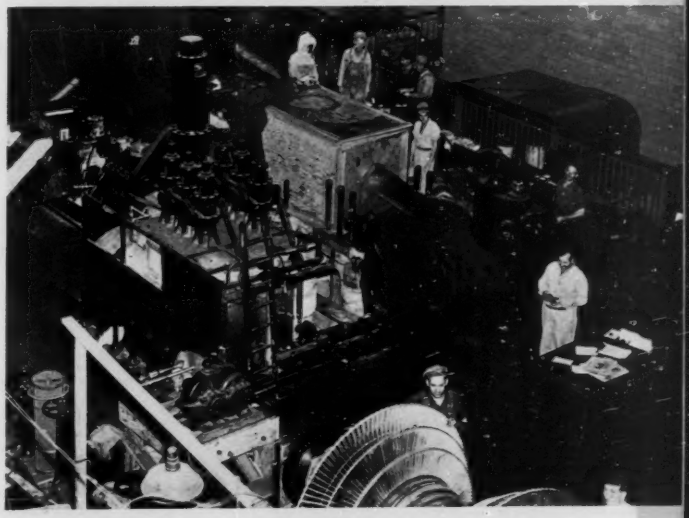
CLEAN blade surfaces are essential to proper inspection of turbine blading by the Zyglo or Magnaflux methods for locating cracks or defects. Clean blades are also desired for full turbine efficiency. In order to obtain the desired cleanliness, especially for inspection purposes, it is usually necessary to clean all the blading which may have surface scale varying from thin oxide films to hard silica deposits. Since hand scraping of blade surfaces is time consuming, it has been found desirable to resort to faster and more effective methods such as blasting with fly-ash. Such methods, however, have met with objection due to the dust problem inside the station. Parts that can be taken outside the station present no serious problem but for non-removable parts the procedure outlined below was found entirely satisfactory and economical.

Development of cleaning techniques

In an effort to overcome these difficulties a set-up was first devised by our steam plant maintenance forces whereby the stationary blades could be sand blasted. (Note: fly-ash was presumed to be too dusty for visibility inside of a small space.) This method proved better than the hand scraping, yet was not completely satisfactory because of the time lost in preliminary preparation and removal of the sand from the machine after cleaning the blades. An exhauster fan was used in an effort to draw out the sand, but even when using number 50 Ottawa core sand of a fineness such that 32 percent passed a 100-mesh screen much of it fell to the bottom of the turbine casing and had to be removed with a vacuum cleaner.

In a final attempt to find a suitable method of cleaning the stationary blading, it was decided to adopt fly-ash as the cleaning material. The fineness and lightness of fly-ash com-

CLEANING STATIONARY TURBINE blading by blasting with fly-ash was impractical at one time because of the excessive dust raised within the station. Today, dust is confined within the airtight, easily fitted hut which is placed over the shell. Dirt particles are then evacuated by a portable exhaust fan to a vacuum bag outside the station. **(FIGURE 1)**



EQUIPMENT USED in the fly-ash method of cleaning can be improvised from materials ordinarily used by the maintenance crew right on the premises. The cost incurred is negligible and the time it takes to set up the equipment is very short. Plywood, rubber hose and tube, pipe, exhaust fan, dust bag, and an air hose are the principally needed supplies. **(FIGURE 2)**

bined with its cleaning quality seemed to give a ready answer to the problem.

A cover or hut (Figures 1 and 2) was first constructed of one-half inch plywood of sufficient size to cover the entire portion of the stationary blading. The cab was then made airtight at all joints, including where it rested on the turbine shell. One end was left open and covered with a drop cloth. In the other end a twelve-inch hole was cut to receive a flexible tube through which the fly-ash was removed by an exhaust fan. The cleaning nozzle shown in Figure 3 was made in the plant shop of extra heavy pipe fittings employing the aspirator principle. Compressed air at 90 lbs per square inch was supplied to the nozzle. The fly-ash was picked up by the vacuum set up by the aspirator from an open bin as shown in the foreground of Figure 1. The intake end of the ash supply line, a 1¼-inch ID air hose, was reinforced with a short piece of pipe. During the operation, the fly-ash was continually agitated to prevent a void from forming in the bin and cutting off the ash supply.

SHELL COVER affords sufficient work space for the operator. Opening directly above his head evacuates dust through a 12-inch flexible tube. Canvas hood has a sight window and is equipped with an air hose which supplies operator with compressed air at atmospheric pressure. **(FIG. 3)**

DUST COLLECTING BAG and blower can be placed in or outside the station. If not a part of the maintenance department equipment, they can be obtained from furnace cleaning companies for a nominal fee. **(FIG. 4)**

Disposing of fly-ash

The ash laden air inside the cab was evacuated by a portable exhaust fan of 6,400 cfm capacity, placed just outside of the turbine room. The dust collecting bag was 40 feet long and seven feet in diameter. These can be rented from furnace cleaning companies. During the first run of this equipment, a bag failure was experienced. It was found that the ash formed a coating on the inner side of the bag, preventing the free passage of air. This was overcome by placing a one-foot section of 12-inch pipe in the far end of the bag as a vent with only a small trickle of ash being discharged. A 12-inch flexible tube was used to carry the ash-laden air from the point of operation to the blower, which on this job was about 150 feet. It is not necessary to place the blower and bag outside the plant as long as the bag is vented to the atmosphere.

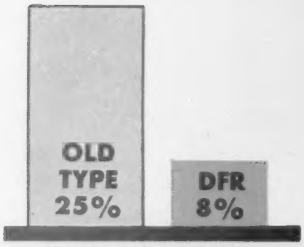
During the cleaning operation, the blower unit was run at approximately one-third speed to enable the workman inside the cab to work with maximum visibility and also to permit the drop cloth to be opened in the entrance of the cab to permit free flow of air. To provide the operator with air, a special hood was made of heavy canvas equipped with a sight window and air hose through which compressed air was delivered by a regulator to approximate atmospheric pressure.

Fly-ash cleaning saves time

With this equipment set-up, 19 rows of blading were cleaned to the native metal in approximately four hours. The scale found on the first 13 rows of blades was thin and hard, requiring considerable effort to remove with a scraper. Setting up and removing the fly-ash blasting equipment and cleaning out that portion of the ash which remained in the shell of the turbine required a total of eight hours. During the 12 hours required for the complete blade cleaning job, other phases of the overhaul work were carried on. This method of removing the fly-ash insures a dust-free atmosphere about the open turbine and generator. Figure 3 shows the operator actually cleaning and blading. Figure 4 shows the portable exhaust fan and a portion of the dust collecting bag. The fly-ash was obtained from the ash hopper under electrostatic ash precipitators and is of a fineness that 70 percent passes a 325-mesh sieve.

This method proved very satisfactory in that the total required elapsed time was a minimum, no lost time was experienced on other phases of the turbine work, and the resulting cleanliness of the blade far surpassed that of the old hand scraping method. Also, when the turbine was brought on load, it appeared probable that the steam rate had been improved a measurable amount over what it had been in previous overhauls when the stationary blading was hand cleaned. The men in the Union Electric system responsible for this development are to be congratulated on a good job.

Boost Line Capacity...



% Excitation Requirements
Based on Regulator KVA

Cut Regulator Kilovar Requirements 2/3 With DFR*—The Only Single Phase Step Regulator

IT WAS ALWAYS GOOD economics to cut reactive kva. *Now* it's a necessity! Loads on utility systems are steadily going up. New equipment is still hard to get. So — why add to your already overburdened lines with more kilovars, when every last watt is needed? Release system capacity for pay loads!

It will pay you to use modern DFR regulators because they require only 8% excitation, compared with 25% required by old type single-phase regulators. You'll be amazed to find how much the high exciting current required by old type regulators is costing you. Figure these costs on the basis of $10 per installed kva for capacitors needed to balance high exciting current.

The modern Allis-Chalmers DFR regulator with its thirty-two 5/8% steps holds ± 1 volt band widths — provides the same close, reliable control successfully used to regulate over 5 million kva.

For further information on this modern economical control, call your nearby A-C office, or write ALLIS-CHALMERS, MILWAUKEE 1, WIS.

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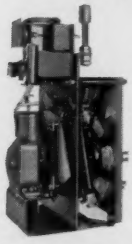
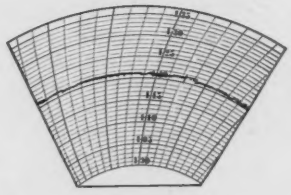


A RUGGED, self centering, shock absorbing, quick-break mechanism is employed in the DFR regulator. Mechanism is immersed in oil — self lubricated — dirt free.



HOLDS ± 1 VOLT BAND. The DFR is unhindered by the limitations of conventional voltage relays or motor brakes to prevent overshooting or hunting.

*DFR — the only station type step regulator you can buy for single phase duty. Sizes to 6900 v, 250 kva. For 3 phase regulation there is the AFR.

ALLIS-CHALMERS

"Originators of the 5/8% Step Regulator!"

W. A. YOST
STEAM TURBINE
C

"Headquarters for Motors ½ to 25,000 hp and Over!"

Do You Need General-Purpose, squirrel-cage motors from 1 to 200 hp? Call either your nearby Allis-Chalmers *Authorized Dealer* or District Office. They may be able to help you from stock right now!

But For Large Ratings—250 to 25,000 hp and over—your Allis-Chalmers *field engineer* is the man to call. He can give you *expert* motor advice; help you solve difficult drive problems involving large or small motors. And he'll save you time and money.

Allis-Chalmers Motor-Building capacity has been greatly increased. New methods, new equipment have been put to work to turn out *good* motors in greater numbers.

And Our Delivery Situation is improving! For *reliable* delivery information call any of over 60 District Offices or over 200 Allis-Chalmers Dealers. They have *up-to-the-minute* delivery information available to them!

Building Good Motors for Over 50 Years

THE *QUALITY* of Allis-Chalmers motors is best proven by their records of performance. Look back at your own experience, or ask your friends in industry who have "A-C" motors what they think of them. The answer is invariably the same . . . "They're *good* motors, liberally designed, easy to service, and run year-after-year with little attention."

Whether you're buying ½ hp motors to be designed into your product . . . or a 25,000 hp motor for a steel mill you can rely on the *good* quality of "A-C" motors! ALLIS-CHALMERS, MILWAUKEE.

A 2400

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One of the Big 3 in Electric Power Equipment—Biggest of All in Range of Industrial Products